



INNOVATIVE BIOMIMETIC ROBOTS FOR HUMAN COLLABORATION

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BIOMIMETICS: CAPTURING THE ESSENCE OF NATURE

NEKTON ALSO WISHES TO THANK:

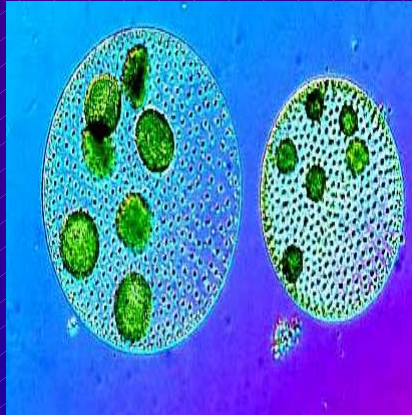
**S.A.WAINWRIGHT
DARPA
US OFFICE OF NAVAL RESEARCH
DEPARTMENT OF ENERGY
US ARMY**



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BIOMIMETICS

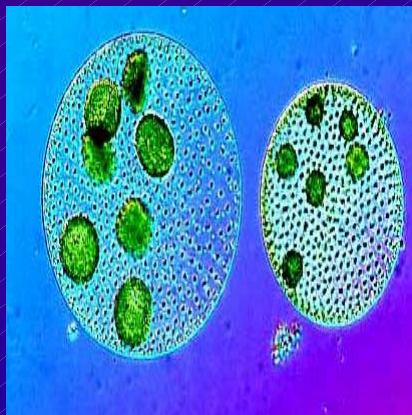
- **DEFINITION**
- **WHY COPY NATURE?**
- **FISH STORY**
- **PARAMECIUM**
- **LESSONS**
- **RECOMMENDATIONS**



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BIOMIMETICS:

EXTRACTING USEFUL PRINCIPLES
FROM NATURE'S PROVEN SOLUTIONS,
AND APPLYING THEM IN A
TECHNOLOGICAL CONTEXT FOR
HUMAN BENEFIT



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POINTS OF DEPARTURE

- LIVING MACHINE'S ABILITIES CAN EXCEED THOSE OF OUR OWN
- ASSUME THAT NATURE WORKS USING "PROVEN" SOLUTIONS
 - PHYSICS RULES, SO WE CAN COPY FUNCTIONS FOR OUR OWN USE
- HOW CAN WE INTERFACE WITH THESE?



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BIOLOGICAL SOLUTIONS:

1. PHYSICS-BASED DESIGN PERMITS ANALYSIS
2. OPTIMIZATION VIA COMPETITION:
 - "THE **GOOD** DESIGNS EAT THE **BAD** ONES"
 - S.A. WAINWRIGHT, 1978
3. CANNOT ASSUME HER SOLUTIONS ARE OPTIMAL
 - MULTIFUNCTIONAL — COMPETING NEEDS
 - FUNCTION OVER GROWTH: 1 CM ($Re\ 10^2$) TO 3M ($Re\ 10^7$)
 - HAND-ME-DOWNS: NO *TABLA RASA* SOLUTIONS
4. NO TELEOLOGY: SELECTION ACTS ON VARIATIONS
5. "GOOD ENOUGH" — NOT PERFECT, COSTS KEPT LOW
6. NATURE MAY BE SOLVING DIFFERENT PROBLEMS



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BIO VERSUS TECHNO:

BIO-TECHNOLOGY: **HUMAN TECH:**

WET, FLEXIBLE	DRY, RIGID
HETEROGENEOUS	HOMOGENOUS
ANISOTROPIC	ISOTROPIC
CURVED	RECTILINEAR
NONMETALLIC	METALLIC
FACTORIES < PRODUCT	FACTORIES > PRODUCT
MULTIFUNCTIONAL !	FUNCTIONS LIMITED
AMBIENT CONDITIONS	HEAT/PRESSURE
HEALING	REPAIR/REPLACE
ETC.	ETC.



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SUCCESSFUL BIOMIMETICS:

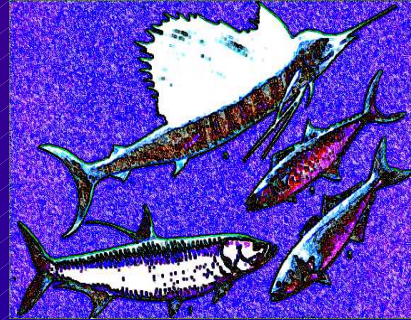
**REQUIRES A BIOLOGIST TO HELP EXTRACT
THE ESSENTIAL PIECES OF THE PUZZLE
FROM THE EVOLUTIONARY,
DEVELOPMENTAL, AND METABOLIC
BAGGAGE**



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FISH STORY

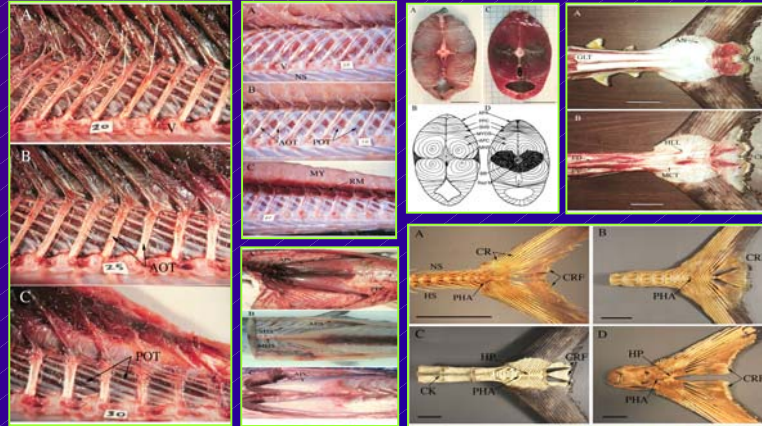
- JOB WAS TO CREATE A SWIMMING FISH
BY COPYING RELEVANT STRUCTURES
- BEGAN BY RENDERING THE COMPLEX 3D
MUSCULATURE, SKELETON, AND
COLLAGEN RIGGING OF THE WORLD'S
FASTEST FISHES (FROM CASTS, X-RAYS,
DISSECTIONS, HISTOLOGY, LITERATURE)



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FISH STORY

SOME RELEVANT STRUCTURES:



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FUNCTIONAL MORPHOLOGY

PRACTICAL EXTRACTION = **ABSTRACTION**



NEED TO SIFT THE **ESSENTIAL FEATURES**
CONTRIBUTING TO THE FUNCTION OF INTEREST
FROM THE 1000'S OF OTHER FEATURES



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MODELING: ABSTRACTION

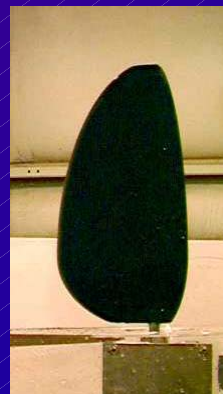
RED V.S. MODEL
REAL B.B. W/FIBERS
BLUE V.S. MODEL W/FIBERS
M.H.S. MODELS/PHOTOS
WORKING TUNA MODEL
COMPLEX FOLLOW-UPS
THEN...



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TWIDDLEFISH/NEKTOR

- ***ALMOST* NO STRUCTURE TO SPEAK OF**
- **QUANTIFIED CLOSE MATCH SHAPE, FLEX. STIFFNESS**
- **BUT: A KEY PROPERTY OFF BY FACTOR OF 1,000...**
- **!!! PERFORMANCE BETTER THAN $\frac{1}{2}$ OF REAL ONES**
- **REQUIRES JUST ONE CHANNEL OF CONTROL**



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BOUNTY OF RESULTS

- ARTIFACTS DISCOVERED, DESCRIBED
- NOVEL PHENOMENA ENCOUNTERED
- FUNDAMENTAL PRINCIPALS UNCOVERED AND QUANTIFIED
 - FEEDBACK FOR BIOLOGY
 - NEW QUESTIONS
 - NEW RESULTS
- **SPIN-OFF TECHNOLOGY: MANEUVERING THRUSTERS, NEKTORS™**



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NEKTORS

MANEUVERING THRUSTERS

- SIMPLE
- QUIET
- THRUST IN ANY DIRECTION
- **4 NEKTORS = HOLONOMIC MOTION**
- COMPARED TO PROP OF = SWEEP AREA:
 - >> 4 TIMES THE THRUST
 - << 1/10TH THE TIME
- DOES A **DIFFERENT JOB** THAN PROPELLERS
- ALSO PERMITS AMPHIBIOUS APPLICATIONS



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NEKTORS

MANEUVERING THRUSTERS

- **SIMPLE, BUT:** FULL DESCRIPTION OF THE DYNAMICS ARE VITAL FOR PROPERLY EXPLOITING THE BEHAVIOR SPACE



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PILOTFISH, GAMERA, DRAGONFLY, ETC...

NEW CLASS OF AGILE VEHICLES (VIDS)

BIOMIMETIC PORTIONS:

- 3 UNSTEADY THRUST MECHS
- ANAEROBIC POWER LEVELS
- FINS ON PERIPHERY

DUMPING NATURE:

- USE OF ROTARY MOTORS

**GOAL: SIMPLEST MERGING
OF BEST OF BOTH WORLDS**



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FISH STORY, CONCLUSION

VERY LITTLE WAS REQUIRED FOR FUNCTION,
NO ANATOMICAL FEATURES NEEDED

SHAPE, MATERIALS, 1 AXIS OF ACTUATION, 1
CHANNEL OF INFORMATION OUT...

(NOTE: ALL MORPHS WORK, WATER *AND* AIR)

BIG PROBLEM: CONTROL



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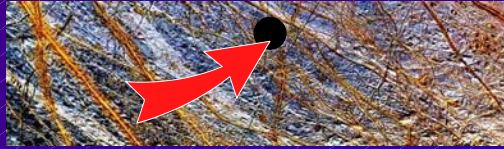
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EUROPA U.I. MISSION = AUV



- **TOTAL MASS BUDGET:**
 - 350 KILOS FOR LANDER + PAYLOAD
 - 60 KILOS FOR CRYOBOT + PAYLOAD
 - ROUGHLY 2 KILOS FOR HYDROBOT (MAUV)
- **BEST CURRENT SMALL AUV (WHOI'S REMUS) MASSES ~ 35 KILOS (~20X TOO LARGE)**
- **MISSION REQUIRES ENABLING TOOL**



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NEEDED: TINY AUV



- **MUST BE AT LEAST AN ORDER OF MAGNITUDE SMALLER THAN ANYTHING NOW FIELDIED**
- **MUST BE EASY-LAUNCH: CREW IS 1-LIGHT-HOUR AWAY; CANNOT RETRIEVE IT**
- **"50% RULE" — NEED AT LEAST TWO SUBS**
- **LOSSES HIGHER UNDER ICE**
- **FULLY FUNCTIONAL (NAV, COM, ETC)**



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AND...
K.I.S.S.



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**DOES NATURE OFFER
ANY SOLUTIONS?**

- **UNICELLULAR ORGANISMS POSSESS 3D GUIDANCE “SOFTWARE” THAT PERMITS THEM TO FIND FOOD, MATES, AND GENERALLY AVOID DEATH**
- **VERY SIMPLE: THEY ARE CELLS**
- **EUKARYOTES, PROKARYOTES, AND SPERMATOOZA**
- **ORIENTATION MECHANISM *THOUGHT* TO BE *B.R.W.***



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PARAMECIUM GUIDANCE

- **KNOWN FOR 100 YRS: FREE-SWIMMING ORGANISMS <1 mm SWIM IN A HELICAL PATTERN ($Re \ 10^{-1}$)**
- **CRENSHAW, 90'S: 3D, KINEMATIC, NONRANDOM MODEL SUCCESSFULLY PREDICTS BEHAVIORS**
- **WORKS DOWN TO ~ 10 MICROMETERS (RDL)**
- **A TRUE TAXIS**
- **OUR CHALLENGE: EXTRACT PARAMECIUM'S METHOD AND USE IT FOR MICRO-AUV GUIDANCE AT REYNOLDS NUMBERS ABOVE 10^5**



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MECHA-PARAMECIUM?

- **COULD ATTEMPT TO COPY MORPHOLOGY COMPLETE WITH CILIA — A RATHER *TEDIOUS PATH***
- **METHOD REQUIRES ONLY HELICAL TRAVEL = DUMP MORPHOLOGY; ACHIEVED H.T. VIA OTHER MEANS (A PROP AND A FIN)**

GOAL: SINGLE CHANNEL OF CONTROL FOR 3D GUIDANCE



70-gram AUV, range >30 kilometers, speed is $\sim 1 \text{ ms}^{-1}$, depth-rated to 100 meters ---

Has just one moving part



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MICROHUNTER MAUV

- PRACTICE IN 8 M TONS OF SILICONE OIL TO COPY REYNOLDS NUMBER ~ SCRATCHED
- TRIED WATER, GOT GOOD ROUGH RESULTS
- HAD TO CREATE DYNAMIC MODEL OF MAUV
- NEW (NON-MICRO) PROBLEMS MET AND SOLVED
- **SUCCESS: SAME RULE WORKS AT $Re \gg 10^5$**
- PERMITS CURRENT RECORD FOR WORLD'S SMALLEST AUV (SHOW VID)



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MICROHUNTER MAUV

- VERY SIMPLE, **BUT:**
- CONTROL IS NON-INTUITIVE
- MECHANISM IS ROBUST WHEN TUNED PROPERLY, **BUT---**
- IT MUST BE TUNED PROPERLY
- SIMPLICITY HAS IT'S OWN PRICE



Micro-AUV possess acoustic link, performs CTD, 3D search patterns as defined by the user



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LESSONS

- CAN EXTRACT NATURE'S TRICKS
- HUGE CHANGES IN CONTEXT POSSIBLE
- MUST CAREFULLY DUMP MOST OF NATURE'S DESIGN BAGGAGE
- BIOLOGISTS ESSENTIAL TO DISCRIMINATE WHEAT FROM CHAFF THROUGHOUT EFFORT
- TECH DEVELOPMENT PATH FEEDS BACK TO BIO RESEARCH, WHICH FEEDS BACK TO TECH, ETC.
- KISS PRINCIPLE VITAL TO SUCCESS, BUT ---
- CONTROL CHALLENGE IS THE PRICE PAID FOR RESULTING "SIMPLE" DESIGNS



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RECOMMENDATIONS

- TRUE INTERDISCIPLINARY TEAMS REQUIRED
- BRING THE BIOLOGISTS IN ON TECHNOLOGY DEVELOPMENT FROM START TO FINISH
- MANY SOLUTIONS ARE TO BE FOUND IN UNEXPECTED CONTEXTS
- **MANY SOLUTIONS (OR EXTREMA THEREIN) ARE NOT EXPLOITED BY ORGANISMS**
- **THOSE THAT ARE, MAY NOT BE OPTIMAL, OR EVEN DESIRABLE ~ DIFFERING MOTIVES**
- STATE PROBLEMS AS FUNDAMENTALS
- SEPARATE HIGH-LEVEL/LOW-LEVEL CONTROL (REQUIRED BY T.O.F. DELAY *AND* TOPOLOGY)



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